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(54) Title of the Invention: DISCHARGE EXCITATION SHORT-PULSE LASER DEVICE

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Specifications

1. Title of the Invention: Discharge Excitation Short-Pulse Laser Device

2. Scope of the Claim of the Invention

(1) A discharge excitation type of a short pulse laser device, characterized by the fact that a first main discharge electrode is mounted in the longitudinal direction to the axial direction of the laser light in the laser gas current,

a second main discharge electrode having a plurality of perforated parts is mounted opposite the first main discharge electrode,

a dielectric layer is deployed tightly attached to the back surface of the second main discharge electrode,

and an auxiliary electrode is deployed opposite the second main discharge electrode tightly attached to this dielectric;

wherein a heat radiating fin is deployed at least for said auxiliary electrode or said dielectric,

using a construction comprising a pulse circuit enabling to apply a pulse voltage between said main discharge electrodes, wherein said pulse circuit is formed as a part of this construction, or this pulse circuit is formed independently;

equipped with a circuit enabling to apply voltage between said auxiliary electrode and said second main discharge electrode.

(2) The discharge excitation type of a short pulse laser device described in claim 1, characterized by the fact that a heat radiating fin is mounted in the laser gas current.

3. Detailed Explanation of the Invention

(Sphere of Industrial Use)

The subject of this invention is a discharge excitation type of a short pulse laser, in particular it relates to cooling of the electrode part of the laser.

(Prior Art Technology)

Figure 4 shows a profile view explaining one example of an excimer laser device according to a conventional discharge excitation type of a short pulse laser device. As shown in the figure, (1) is a source of high voltage, numbers (2), (5), and (7) indicate capacitors, (3) is a

high resistance resistor, (4) is a switch, (6) is a coil, (9) is a first main discharge electrode mounted in the longitudinal direction of the axis of the laser light (vertical direction to paper surface) deployed in a current of laser gas, (8) is a second main discharge electrode, that is to say a perforated electrode provided with openings which has a part provided with multiple openings and which is mounted opposite the first main discharge electrode (9), (11) is a dielectric which deployed so that it is tightly attached to the back surface of perforated electrode (8), (10) is an auxiliary electrode positioned opposite perforated electrode (8), mounted so that it is tightly attached to this dielectric (11), (12) is a heat exchanger, (13) is a fluid guide, (14) is a fin, (15) is a laser housing unit, (16) is an insulator, (17) is a space for the main discharge, and arrow (18) indicates the direction of the laser gas.

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In addition, Figure 5 shows a top view of said perforated electrode (8) seen from the main discharge space (17). Number (19) indicates in this figure the perforated part.

The following is an explanation of the operation.

The circuit system will be explained first. When a charge is furnished from a high-voltage source (11), the charge will be first stored in capacitor (2). Next, switch (4) is activated so that the electric charge which has been stored in capacitor (2) will be transferred to capacitor (5) through switch (4) setting the conductive state from capacitor (2) continuing through a grounding line to capacitor (5) and coil (6), and furnishing charge stored in capacitor ( 2) to capacitor (5).Accompanying this prompt transfer of the electric charge will be a sudden increase of the voltage in the space between perforated electrode (8) and the first main discharge electrode (9) (hereinafter referred to as the electrode space between the main discharge electrodes) and perforated electrode (8) and auxiliary electrode (10) (hereinafter referred to as the electrode space between the auxiliary electrodes).Because the initial voltage of the auxiliary electrodes is lower than the initial voltage of the main discharge electrodes, first, an auxiliary discharge will be initiated on the surface (electric discharge along the surface area) of dielectric (11) in the perforated part (19) created in perforated electrode (8). One part of the electrons generated by this auxiliary electrode and electrons generated by ionization with ultraviolate light rays emitted from the field of the electric discharge will be used to create a homogenous glow state of the main discharge. Next, the main discharge generated in the main discharge space (17) in a pulse form will excite a laser medium and laser light rays will be fetched as a result of this. The pulse width of this laser light is determined by the pulse width of the main discharge. To give an example, this will correspond to several tens of nsec in an excimer laser at the point when 1 short pulse of the laser is created. A common thyratron type can be used for switch (11) with a laser pulse oscillation frequency in the range of several Hz to several kHz. Normally, a repeating speed of several hundred Hz can be used.

The fluid system will be explained next. Because the main discharge electrode space (17) in which the main discharge is generated in a pulse form will be generally in an unstable state from the viewpoint of thermal energy and from the viewpoint of the distribution of the electric charge, the next pulse main discharge can easily create an arc and the laser gas thus must be replaced in the main discharge space (17) before the main pulse discharge is generated. Because of that, a heat exchanger (12) is deployed in order to prevent increased temperature caused by the discharge of laser gas, together with a fluid guide (13) and fin (14), creating a construction wherein the flow rate in the space of the discharge enables a high speed of the gas current (18), normally several tens m every second.

The cooling of perforated electrode (8) and dielectric (11) can be accomplished in this prior art example only by the heat transfer with natural convection in back face space (12) via the back face of auxiliary electrode (10) and with the turbulence heat transfer in said gas current (18). On the other hand, the space in which the auxiliary discharge and the main discharge is generated along the surface on the side of perforated electrode (8) will form a surface to which heat will be input.

If one attempts to calculate the order of heat input by using excimer lasers as an example while taking into account a laser pulse energy of 200 mJ/pulse and a machine type which has a mean output of 200 W with a repeating speed of 1 kHz, the normal laser oscillation efficiency will be 1%. Therefore, the energy stored in capacitor (2) will correspond to 20 kW. If the ohmic loss in the circuit system is about a half, 10 kW will be input to the gas. This means that the result will be on the order of several hundred W even if the heating source is formed in the part of perforated electrode (3), which means that barely several % of the total is achieved.

On the other hand, if one attempts to calculate also the turbulence heat transfer conditions (for instance as described by Yoshiro [illegible last name], in Heat Transmission Equipment, published by [illegible name of the publishing house], p. 116 (1982)), by using Kalman's analog method based on Nusselt's number (expressed as $N_u^x$), Reynold's number (expressed as $R_e^x$), Prandtl's number (expressed as $P_r$), local heat transmission rate (called $h^x$), heat conductivity of fluids (expressed as $\lambda_{He}$) with helium gas can be used for test calculations( because helium composition represents at least 90% of a common excimer laser), at the end of the gas current flow period of perforated electrode (8), the local heat transmission rate can be calculated by using all the following variables with the distance (expressed as x) up to upper part of perforated electrode (8):

[insert Formula (1) and formula (2) at the bottom of page 452]

The pressure of He can be set to 3 atmospheres, which corresponds to normal operating pressure of excimer lasers, and the gas flow rate can be set to a normal flow rate of 20 m/sec for an excimer laser, the width of the shape of perforated electrode (8) can be set to 0.06 m, and the length in the direction of the optical axis of the laser rays to 0.6 m. Assuming a distance x of 0.03 m, that is to say when a central point is set for the electrode with, Reynold's number ($R_e^x$) will

correspond to 1.6 x $10^4$.

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In addition, because Prandtl's number (expressed as $P_r$) for gases corresponds to 0.7 for helium, resulting in heat conductivity of 0.13 kcal/mhr °C, this means that local heat transmission rate $n^x$ can be calculated as 2.8x $10^2$ kcal/$m^2$ °C.

Assuming that the difference between the temperature of helium gas and the temperature of perforated electrode (8) is for example 20°C, the quantity of heat that will be removed will correspond to about 200 W, which is only about the same or less than the above described heat input.

In addition, if this set temperature difference is 20°C and perforated electrode (8) is manufactured for instance from nickle (because this is the most desirable material for excimer lasers), since its linear expansion coefficient is 0.15 x $10^{-4}$, perforated electrode (8) will be also expanded by 0.2 mm. Since a perforated electrode is generally used with a construction wherein it is tightly attached to dielectric (11), so called "cambering" will be displayed due to this elongation in perforated electrode (8) and dielectric (11) as the attachment of dielectric (11) to perforated electrode (8) will not occur smoothly.

(Problems To Be Solved By This Invention)

Because discharge excitation laser devices of the short-pulse type according to prior art were characterized by the above described construction, when the repeating speed was increased in order to increase the mean laser output and heating was applied to perforated electrode (8) and dielectric (11), this would result in rupturing of dielectric (11) due to thermal stress and cambering of perforated electrode (8). And because this in turn resulted in an uneven length of the gap between the main discharge electrodes, the problem was that an arc of the main discharge electrode could easily occur in this manner.

The purpose of this invention is to resolve the above mentioned problem area with a simple method enabling cooling of the perforated electrode and of the dielectric to make it possible to obtain a discharge excitation type short-pulse laser device enabling stable operations even when the repeating speed of laser oscillations is increased.

(Means To Solve Problems)

According to the discharge excitation short-pulse laser device of this invention, a first main discharge electrode is mounted in the longitudinal direction to the axial direction of the laser light in the laser gas current, a second main discharge electrode having a plurality of

perforated parts is mounted opposite the first main discharge electrode, a dielectric layer is deployed tightly attached to the back surface of the second main discharge electrode, and an auxiliary electrode is deployed opposite the second main discharge electrode tightly attached to this dielectric; wherein a heat radiating fin is deployed at least for said auxiliary electrode or said dielectric, using a construction comprising a pulse circuit enabling to apply a pulse voltage between said main discharge electrodes, wherein said pulse circuit is formed as a part of this construction, or this pulse circuit is formed independently; equipped with a circuit enabling to apply voltage between said auxiliary electrode and said second main discharge electrode.

(Operation)

The heat radiating fin of this invention, which will be described in more detail later, provides an optimal cooling effect for the perforated electrode and for the dielectric.

(Embodiment)

The following is an explanation of one embodiment of this invention based on the enclosed figures. Figure 1 (a) [on the left side] shows a profile view indicating one embodiment of this invention, while Figure 1 (b) [on the right side] shows a profile view of a section of the main part of Figure 1 (a) indicated in the upper part of the figure. As shown in the figure, [illegible number] is a heat radiated fil mounted in this example on auxiliary electrode (10).

The operation will be explained in detail next. Perforated electrode (8), dielectric (11) and auxiliary electrode (1) form from the viewpoint of thermal structure a layered construction consisting of 3 layers. If for example nickle is used for perforated electrode (8) and auxiliary electrode (10) and aluminum is used for dielectric (10), the value of the overall coefficient of thermal conductivity will be on the order of $10^4$ kcal.m$^2$ hr°C. As was explained above, this is greater by two digits than the thermal conductivity of the helium gas in perforated electrode (8). Accordingly, the cooling accelerating stage enables to provide an optimal effect thanks to the thermal conductivity transition of the laser gas, as was explained above, more than 90% when for example helium is used in an excimer laser. Moreover, to make it possible to realize a simpler method, it is desirable to use a coolant in the electrode containing a laser gas, while the temperature can be also controlled with heat exchanger (12). First, if a ratio n is set for the gas flow rate and Reynold's number is multiplied n times, even if the resulting thermal conductivity equals approximately n, the problem is that the pressure loss in the discharge space (17) equals $n^2$ (because it will be proportional to the square of the flow velocity).

An example of the cooling of auxiliary electrode (10) will now be considered. As was explained above, due to a high thermal conductivity in the space of [illegible] plates of auxiliary electrode (10) and dielectric (11) and perforated electrode (8), a sufficient cooling effect can be achieved in perforated electrode (8) and dielectric (11) when cooling is applied to auxiliary electrode (10).

In order to do that, a heat radiating fin (20) is mounted on auxiliary electrode (10), so as to conduct the current of laser gas to this laser radiating fin (20). Assuming a surface area A of the auxiliary electrode (10), the surface area of the remaining part which is not provided with a fin (i) is expressed as $A_o$, while a part of A is provided with fin (20), while the total surface area of fin (20) is expressed as $A_f$ and the thermal conductivity of the surface of the fin is expressed as $h_o$, then the thermal conductivity coefficient can be expressed according to the following formula:

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[see Formula (3) in the left top corner of page 454]

The value of the fin effect, which will be called $\eta$ here, will be determined by the thermal conductivity coefficient of the material of fin (2) and by the thermal conductivity coefficient on the surface of fin (2), by the thickness of fin (20) and by the height of fin (20). As one can see from Formula (3), when the shape of the fin is chosen so as to increase $\eta A_f$, this will make it possible to maximize the value h. An example of this concept will now be explained.

If the profile surface area of auxiliary electrode (10) is selected similarly to the surface area of perforated electrode (8) with a width of 0.06 m, a length of 0.6 m is selected in the axial direction of the laser light, and 200 plates of discharge fins (20) which are 0.02 m high and 0.5 mm thick are deployed at an interval of 2.5 mm in a direction orthogonal to the laser light, $A_o$ corresponding to 0.03 $m^2$ and $A_f$ corresponding to 0.48 $m^2$ will be created. In addition, if nickle is used as the material of this fin and the gas flow velocity of the gas passing through the fin part (20) is 20 m/sec, according to Yoshiro Kodo, (Theory of Thermal Conductivity, [illegible name of the publishing house], p. 27 (1982), the thermal conductivity coefficient of the surface of fin (20) will be created with a fin efficiency $\eta$ of 0.86 and it will thus be determined as $2.6 \times 10^2$ kcla/$m^2$. Therefore, since the thermal conductivity ratio h will be determined in accordance with formula (3) as $3.2 \times 10^3$ kcal/$m^2$, this means that the prior art example is improved by as much as 1 digit.

The operation will be explained next. Since the operation of the circuit system has been already explained in Figure 4, this part will be omitted from the explanation provided for Figure 1.

First, laser gas will be circulated with fin (14). The gas discharged into the main discharge space (17) is cooled to a specified temperature by heat exchanges (12) and then it is returned again to the main discharge space (17). However, one part of this gas will be supplied to the part of heat radiating fin (20) which is deployed on the back surface of auxiliary electrode (10) so that cooling will be applied via auxiliary electrode (10) in dielectric (11) and perforated electrode (8). The gas will be mixed again with the gas which has passed through main discharge space (17) and discharge fin part (20) and it will be conducted to heat exchanger (12).

In this embodiment, the thickness of perforated electrode (8) was 0.5 mm, the thickness of the dielectric (11) was 2 mm, and the thickness of the auxiliary electrode (10) was 1 mm, while the values used for the profile surface area of each electrode, for the size of fin (20), and for the gas flow velocity were calculated according to the above explained method for calculation of thermal conductance coefficient.

When no heat radiating fin (20) was deployed while oscillations were generated with a laser pulse energy of 100 mJ/pulse by using an excimer laser with 3 atmospheres (He : Xe : Cl = 0.15 : 0.75 : 99.1), an irregular gap length was obtained between the main discharge electrodes due to cambering caused by the thermal expansion of perforated electrode (8) at the stage when the repeating speed was 300 Hz. While a glow form of the discharge and a filament form of the discharge occurred, the filament shape of the discharge was not generated in this example until the repeating speed of 400 Hz, which proved the efficiency of this cooling method. Needless to say, this difference is likely to be even more conspicuous when the repeating speed is increased again on the order of a kHz.

Figure 2 shows another embodiment of this invention. In this embodiment, main discharge space (17) and heat radiating fin (20) parts are arranged in series in the gas flow channel. Accordingly, while in the case in which both parts were arranged in parallel as shown in Figure 1, the gas current quantity of fin (14) had to be increased only by an amount corresponding to the gas current passing through the heat radiating part (20), the gas current quantity can be left as is in the present embodiment form and the discharge pressure of fin (14) must be increased. The type of mode that is used will be more or less determined by the capability of fin (14).

Figure 3 shows a profile view indicating a heat radiating part according to yet another embodiment of this invention. Auxiliary electrode (10) is embedded in this embodiment in the inner part of dielectric (11). Because this construction is used, heat radiating fin (20) is mounted in dielectric (11). Metal can be used in this case as the material of heat radiating fin (20) in spite of the dielectric.

Furthermore, although the explanation of each of the excimer lasers above pertained to an excimer laser, this invention is applicable also to for instance to TEA $Co_2$ lasers or other discharge excitation types of short-pulse lasers, while the same effect will be achieved as in the above explained examples.

Further, so called punching metal or mesh, etc., can be used for perforated electrode (8) and in addition to the circular shape of the perforated part (19) it is also possible to use an elliptical shape, or a polygon shape, etc.

(Effect of the Invention)

As was explained above, according to this invention, a first main discharge electrode is

arranged in the longitudinal direction to the axial direction of laser rays in a laser gas current, a second main discharge electrode having a plurality of perforated parts is arranged opposite the first main discharge electrode, a dielectric is arranged closely attached to the back surface of this second main discharge electrode, an auxiliary electrode is deployed opposite this second main discharge electrode and a heat radiating fin is deployed at least for said dielectric or auxiliary electrode;

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using a construction comprising a pulse circuit enabling to apply a pulse voltage between said main discharge electrodes, wherein said pulse circuit is formed as a part of this construction, or this pulse circuit is formed independently; equipped with a circuit enabling to apply voltage between said auxiliary electrode and said second main discharge electrode, which makes it possible to cool with optimal efficiency said dielectric and second discharge electrode with a simple method. The resulting effect is that stable operations can be achieved with a discharge excitation type of a short-pule laser device even when the repeating speed of the laser oscillations is increased.

4. Brief Description of Figures

Figure 1 shows a profile view explaining one embodiment of this invention, wherein Figure 1 (a) [on the left] shows a profile view indicating one embodiment of this invention, while Figure 1 (b) [on the right] shows a profile view of a section of the main part of Figure 1 (a) indicated in the upper part of the figure. Figure 2 shows a profile view explaining another embodiment of this invention, Figure 3 shows a profile view indicating a heat radiating fin part according to yet another embodiment of this invention, Figure 4 shows a profile view explaining a discharge excitation type of a short-pule type of an excimer laser device according to prior art, and Figure 5 shows a top view of the second main discharge electrode shown in Figure 4 shown from the main discharge space.

In these figures, (8) is a second main discharge electrode, (9) is a first main discharge electrode, (10) is an auxiliary electrode, (11) is a dielectric, (18) is an arrow indicating the direction of the current of a laser gas, (19) is a perforated part, and (20) is a heat radiating fin.

Also, the same codes are assigned to the same or corresponding parts in each figure.

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Figure 2, Figure 3, Figure 4, and figure 5

Continuation from page 1:

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[page 457]

Procedural Amendment (Voluntary)

Date: March 6, 1985

To: Commissioner of the Japanese Patent Office

1. Indication of the Item: Patent Application Number Sho 59-239268

2. Title of the Invention: Discharge Excitation Short Pulse Laser Device

3. Amending Party

Relationship to the Item: Patent Applicant
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Name: Masuo Oiwa, patent attorney [personal seal]
[illegible line]

[illegible date stamp]

5. Subject of the Amendment

(1) The column "Detailed Explanation of the Invention"

(2) Figures

6. Content of the Amendment

(1) Line 16 on page 3 of the Specifications, which reads "the initial voltage of the auxiliary electrode is lower than the initial voltage of the main discharge electrode" is corrected to "the voltage at the beginning of the discharge of the auxiliary electrode is lower than discharge voltage at the beginning of the main discharge electrode".

(2) Line 7 ~ line 8 on page 4 of the Specifications, which reads "switch (11)" is corrected to "switch (4).

(3) Line 18 ~ line 19 on page 5 of the Specifications, which reads "Tusselt's number is corrected to "Nusselt's number".

(4) Figure 4 is amended as per a separate appendix.

7. List of Enclosed Documents

Figure (Figure 4) 1 copy

THAT IS ALL

⑲日本国特許庁（JP）　⑪特許出願公開
⑫公開特許公報（A）　昭61－116889
⑤Int.Cl.⁴　識別記号　庁内整理番号　㊸公開　昭和61年(1986)6月4日
H 01 S 3/04　6370－5F
審査請求　未請求　発明の数 1　（全7頁）

⑭発明の名称　放電励起型短パルスレーザ装置

㉑特　願　昭59－239268
㉒出　願　昭59(1984)11月13日

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最終頁に続く

明　細　書

1. 発明の名称

放電励起型短パルスレーザ装置

2. 特許請求の範囲

(1) レーザガス流中に配置され、レーザ光軸方向を長手方向とする第1の主電極、第1の主電極と対向して配設され、複数個の開孔部を有する第2の主電極、第2の主電極の背面に密着して配設された誘電体、この誘電体に密着して配設され、第2の主電極と対向する補助電極、上記誘電体および補助電極の少なくとも一方に設けられた放熱フィン、上記主電極間にパルス電圧を印加するパルス回路、並びに上記パルス回路の一部を形成するか、または上記パルス回路とは独立したものであつて、上記補助電極と第2の主電極の間に電圧を印加する回路を備えた放電励起型短パルスレーザ装置。

(2) 放熱フィンはレーザガス流中に配設されている特許請求の範囲第1項記載の放電励起型短パルスレーザ装置。

3. 発明の詳細な説明

〔産業上の利用分野〕

この発明は、気体レーザのうち放電励起型短パルスレーザを対象とするものであつて、特にその電極部の冷却に関するものである。

〔従来の技術〕

第6図は従来の放電励起型短パルスレーザ装置の一例としてエキシマレーザ装置を示す断面図であり、図において、(1)は高電圧電源、(2)，(6)，(7)はキャパシタ、(3)は抵抗、(4)はスイッチ、(8)はコイル、(9)はレーザガス流中に配置され、レーザ光軸方向（紙面に垂直な方向）を長手方向とする第1の主電極、(8)は第1の主電極(9)と対向して配設され、複数個の開孔部を有する第2の主電極すなわち開孔電極、(10)は開孔電極(8)の背面に密着して配設された誘電体、(11)はこの誘電体(10)に密着して配設され、開孔電極(8)と対向する補助電極、(12)は熱交換器、(13)は流体ガイド、(14)はファン、(15)はレーザ筐体、(16)は絶縁物、(17)は主放電空間、(18)はレーザガス流の方向を示す矢印である。

また、第5図は上記開孔電極(8)を主放電空間(17)から見た平面図であり、図において、(19)は開孔部を示す。

次に動作について説明する。

まず、回路系について述べる。高電圧電源(1)から供給される電荷は、まずキャパシタ(2)に蓄積される。次いでスイッチ(4)が導通状態になるとキャパシタ(2)からスイッチ(4)、さらにアースラインを介してキャパシタ(5)，コイル(6)を経てキャパシタ(2)にもどるという電流ループによつて、キャパシタ(2)に蓄積されていた電荷はキャパシタ(5)に移行される。この急速な電荷の移行に伴つて開孔電極(8)と第1の主電極(9)の間（以下主放電々極間と呼ぶ）および開孔電極(8)と補助電極(10)との間（以下補助放電々極間と呼ぶ）の電圧が急峻に上昇する。補助放電の開始電圧は主放電の開始電圧より低いので、まず開孔電極(8)に設けられた開孔部(19)において誘電体(11)表面に補助放電（沿面放電）が起こる。この補助放電で生成する電子の一部およびこの放電場からの紫外光で光電離されて生ずる電子が、主放電をグロー状の均一な放電とするための種となり、次いで主放電空間(17)においてパルス的に主放電が起つてレーザ媒質が励起され、その結果、レーザ光が取り出される。このレーザ光のパルス幅は主放電のパルス幅によるが、一例をあげれば、短パルスレーザの1つであるところのエキシマレーザにおいては数十nsecである。スイッチ(4)としては通常サイラトロンが用いられ、上記のレーザパルス発振が数Hzないし数kHz、通常は数百Hzのくり返し速度でくり返し行なわれる。

次に流体系について述べる。一般にパルス的に主放電が起つた後は主放電空間(17)は、熱的にも電荷分布の点からも不均一な状態になつており、次のパルス主放電がアークになり易いため、次のパルス主放電が起る前に主放電空間(17)のレーザガスを置き換えておく必要がある。このため、ファン(14)や流体ガイド(13)およびレーザガスの放電による温度上昇を防ぐための熱交換器(12)が配設されており、通常主放電空間における流速が毎秒数十mという高速なガス流(15)が達成されている。

この従来例においては、開孔電極(8)および誘電体(11)の冷却は、上記ガス流(15)による乱流熱伝達と背面の補助電極(10)を介して、背面空間で形成される自然対流による熱伝達によつてしか行なわれない。しかも、開孔電極(8)側は沿面補助放電および主放電が起つている間は、逆に熱入力面となる。

エキシマレーザを例として、熱入力のオーダを試算してみると、レーザパルスエネルギ200mJ/パルス，くり返し速度1kHzで平均出力200Wの機種を考えると、通常レーザ発振効率は1%であるから、キャパシタ(2)に蓄えられるエネルギは20kWとなる。回路系におけるオーミックな損失が半分とすれば10kWがガスに投入される。その内わずか数%が開孔電極(8)部の加熱源になるとしても数百Wのオーダに達する。

一方、乱流熱伝達率を試算してみると、例えば（甲藤好郎，伝熱概論，養賢堂版，116p(1982)）から、カルマンのアナロジ式を用いれば、ヌッセルト数（$N_u^x$ と記す），レイノルズ数（$R_e^x$ と記す），プラントル数（$P_r$ と記す），局所熱伝達率（$h^x$ と記す），流体（一般のエキシマレーザのガス組成はヘリウムが90%以上であるので、試算においてはヘリウムガスとする）の熱伝導率（$\lambda_{He}$ と記す），開孔電極(8)のガス流上流側の端から、今、局所熱伝達率を試算しようとしている開孔電極(8)上のある部分までの距離（xと記す）の関数を用いて

$$N_u^x = \frac{h^x \cdot x}{\lambda_{He}} = 0.0296\, R_e^{x\,0.8} \cdot P_r \Big/ \{1+B(R_e^{x\,-0.1})(P_r-1)\} \qquad (1)$$

$$B = 0.86\left(1+\frac{\ln[(1+5P_r)/6]}{(P_r-1)}\right) \qquad (2)$$

と書くことができる。

Heの圧力を通常のエキシマレーザの動作圧3気圧とし、ガス流速を通常のエキシマレーザでの流速から20m/secとし、開孔電極(8)形状を幅0.06m，レーザ光軸方向の長さ0.6mとする。今、距離xのポイントとして0.03m、すなわち電極幅の中央を設定すると、レイノルズ数（$R_e^x$）は $1.6\times10^4$ となり、また気体のプラントル数は約0.7ヘリウムの熱伝導率は0.13kcal/m h °C であるから、局所熱

伝達係数h'は$2.6\times10^{2}$kcal/m²hr℃と算出される。今、ヘリウムガス温度と開孔電極(8)温度との差を20℃とすると、取り去られる熱量は、約200Wとなり、先述の熱入力と同等もしくはそれ以下にしか満たない。

また、上記設定温度差20℃においては、例えば開孔電極(8)がニッケル(エキシマレーザではもつとも望ましい材料とされている)製であるとすると、その線膨張率$0.13\times10^{-4}$から開孔電極(8)は0.2mmも伸びることになる。一般に開孔電極は誘電体(11)に密着させる構造がとられているので、誘電体(11)上を開孔電極(8)がスムーズにすべらず、上記の伸びは開孔電極(8)の"そり"となつて現われることが多い。

〔発明が解決しようとする問題点〕

従来の放電励起型短パルスレーザ装置は以上のように構成されているので、レーザ平均出力を向上させるためにくり返し速度を増すと、開孔電極(8)や誘電体(11)が加熱され、熱応力による誘電体(11)の破損や、開孔電極(8)の反りによつて、主放電々極間のギャップ長が局部的に不ぞろいになり、主放電がアークになりやすいなどの問題点があつた。

この発明は上記のような問題点を解消するためになされたもので、簡易な方法で開孔電極および誘電体を冷却し、これによつてレーザ発振のくり返し速度を増しても安定に動作する放電励起型短パルスレーザ装置を得ることを目的とする。

〔問題点を解決するための手段〕

この発明に係る放電励起型短パルスレーザ装置は、レーザガス流中に配置され、レーザ光軸方向を長手方向とする第1の主電極、第1の主電極と対向して配設され、複数個の開孔部を有する第2の主電極、第2の主電極の背面に密着して配設された誘電体、この誘電体に密着して配設され、第2の主電極と対向する補助電極、上記誘電体および補助電極の少なくとも一方に設けられた放熱フィン、上記主電極間にパルス電圧を印加するパルス回路、並びに上記パルス回路の一部を形成するか、または上記パルス回路とは独立したものであつて、上記補助電極と第2の主電極の間に電圧を印加する回路を備えたものである。

〔作用〕

この発明における放熱フィンは、以下で詳述するように、開孔電極および誘電体を効率良く冷却する。

〔実施例〕

以下、この発明の一実施例を図をもとに説明する。第1図アはこの発明の一実施例を示す断面図、第1図イは第1図アの主要部をイ－イ方向から見た断面図である。図において、(4)は放熱フィンであり、この例では補助電極(10)に設けられている。

次に作用について詳細に説明する。開孔電極(8)、誘電体(11)、および補助電極(10)は、熱的には三層の積層板を形成している。例えば、開孔電極(8)と補助電極(10)の材質をニッケルとし、誘電体(11)の材質をアルミナとすると、総括的な熱伝達率の値は、$10^{4}$kcal/m²hr℃のオーダとなり、先述の開孔電極(8)からヘリウムガスへの熱伝達率より二桁大きい。したがつて、冷却の律速段階は、レーザガス(先述したように例えばエキシマレーザでは90%以上がヘリウム)への熱伝達過程であり、この過程を速めてやればより効率の良い冷却が可能となる。しかも、より簡易な方法でこれを実現するには、高速で循環され、かつ熱交換器(9)で温度制御されているレーザガスを電極部の冷媒とするのが望ましい。まず、ガス流速をn倍にすれば、レイノルズ数がn倍になり、結果として熱伝達率も約n倍になるが、その一方では主放電空間(7)における圧力損失が(流速の2乗に比例するので)$n^2$倍にもなり問題である。

そこで補助電極(10)を冷却する事を考える。先述したように、開孔電極(8)と誘電体(11)と補助電極(10)の積層板間の熱伝達率は大きいので、補助電極(10)を冷却することにより開孔電極(8)および誘電体(11)の効果的な冷却は十分行なえる。

このために補助電極(10)に放熱フィン(4)を設け、この放熱フィン(4)にレーザガスを流すようにした。

今、補助電極(10)の面積を$A$、この$A$のうちフィン(4)を設けた際にフィン(4)がついていない残りの部分の面積を$A_0$，フィン(4)の全面積を$A_f$，フイ

ン表面の熱伝達率を$h_0$とすると、熱伝達係数は次式で与えられる。

$$h = \frac{A_0 + \eta A_f}{A} h_0 \qquad (3)$$

ここで、$\eta$はフィン効率と呼ばれ、フィン(20)表面の熱伝達率とフィン(20)材料の熱伝導率，フィン(20)の厚み，フィン(20)の高さによつて決まる値である。(3)式から明らかなように$\eta A_f$を大きくするようにフィン形状を選ぶことによつてhを極めて大きくすることができる。一例を以下に示す。

補助電極(10)の断面積を先述の開孔電極(8)と同様に、幅0.06m，レーザ光軸方向の長さ0.6mとし、これに高さ0.02mで厚み0.5mmの放電フィン(20)を2.5mm間隔でレーザ光軸と直交する方向に200枚設けたとすると、$A_0$は$0.03m^2$，$A_f$は$0.48m^2$となる。また、フィン材料をニツケルとし、フィン(20)部を通過するガス流速を20m/secとすると（甲藤好郎，伝熱概論，養賢堂版，27p（1982））よりフィン効率$\eta$は0.86，フィン(20)表面の熱伝達率$h_0$は$2.6\times10^2$kcal/m$^2$hr℃となるから、熱伝達率hは(3)式より$3.2\times10^3$kcal/m$^2$hr℃となり、従来例に比べて1桁も大きくなる。

次に動作について説明する。回路系の動作は第4図において説明したので第1図においては省略した。

まず、レーザガスはファン(14)によつて循環されている。主放電空間(17)を出たガスは熱交換器(12)で所定の温度に冷却され再び主放電空間(17)に戻されるが、その一部は補助電極(10)の背面に設けられた放熱フィン(20)部に送られ補助電極(10)を介して誘電体(11)および開孔電極(8)の冷却を行う。主放電空間(17)および放熱フィン(20)部を通過したガスは再び混合され、熱交換器(12)へと導かれてゆく。

この実施例においては開孔電極(8)の厚み0.5mm誘電体(11)の厚み2mm，補助電極(10)の厚み1mmであり、各電極の断面積，フィン(20)の大きさ，ガス流速は先述の熱伝達率の試算で用いた値と同じである。エキシマガス3気圧（He:Xe:Cl=0.15:0.75:99.1）を用いてレーザパルスエネルギ100mJ/パルスの発振を行つた際、放熱フィン(20)を設けなかつた場合は、くり返し速度300Hzの段階で、開孔電極(8)の熱膨張による反りに起因する主放電々極間のギャップ長の不ぞろいができ、グロー状の主放電に混つて、フイラメント状の放電が起つていたが、この実施例においては、400Hzまでくり返し速度をあげてもフイラメント状の放電は発生せず、この冷却方法の有効性が証明された。くり返し速度をさらにkHzオーダにまで増した際には、この差はさらに顕著なものになるであろうことは言うまでもない。

第2図はこの発明による他の実施例を示し、この実施例においては、ガス流路において、主放電空間(17)と放熱フィン(20)部が直列に配設されている。したがつて、第1図のように両者が並列に配設されている場合には、ファン(14)のガス流量を放熱フィン(20)部通過ガス流に相当する量だけ増さねばならないのに対し、この実施例ではガス流量はそのまゝでよいが、ファン(14)の吐出圧力を増してやらねばならない。何れの形態を取るかは、むしろファン(14)性能から決定されるものである。

第3図はこの発明のさらに他の実施例に係る放熱フィン部を示す断面図であり、この実施例においては補助電極(10)が誘電体(11)内部に埋め込まれた構造となつているため、放熱フィン(20)は誘電体(11)に設けられている。この場合の放熱フィン(20)の材料は、誘電体であつても金属であつてもよい。

なお、上記実施例では何れもエキシマレーザの場合について主に説明したが、この発明は例えばTEA $CO_2$レーザなど他の放電励起型短パルスレーザにも適用でき、上記実施例と同様の効果を奏する。

また、開孔電極(8)としてはパンチングメタルやメッシュなどを用いることができ、開孔部(9)の形状は円形の他、だ円形や多角形などであつてもよい。

〔発明の効果〕

以上のように、この発明によれば、レーザガス流中に配置され、レーザ光軸方向を長手方向とする第1の主電極，第1の主電極と対向して配設され、複数個の開孔部を有する第2の主電極、第2

の主電極の背面に密着して配設された誘電体、この誘電体に密着して配設され、第2の主電極と対向する補助電極、上記誘電体および補助電極の少なくとも一方に設けられた放熱フィン、上記主電極間にパルス電圧を印加するパルス回路、並びに上記パルス回路の一部を形成するか、または上記パルス回路とは独立したものであつて、上記補助電極と第2の主電極の間に電圧を印加する回路を備えたので、簡単な方法で第2の主電極および上記誘電体を効率よく冷却することができ、その結果、レーザ発振のくり返し速度を増しても安定に動作する放電励起型短パルスレーザ装置が得られる効果がある。

4. 図面の簡単な説明

第1図(ア)はこの発明の一実施例を示す断面図、第1図(イ)は第1図(ア)の主要部をイ－イ方向から見た断面図、第2図はこの発明の他の実施例を示す断面図、第3図はこの発明のさらに他の実施例に係る放熱フィン部を示す断面図、第4図は従来の放電励起型短パルスレーザ装置を示す断面図、第5図は第4図に示す第2の主電極を主放電空間から見た平面図である。

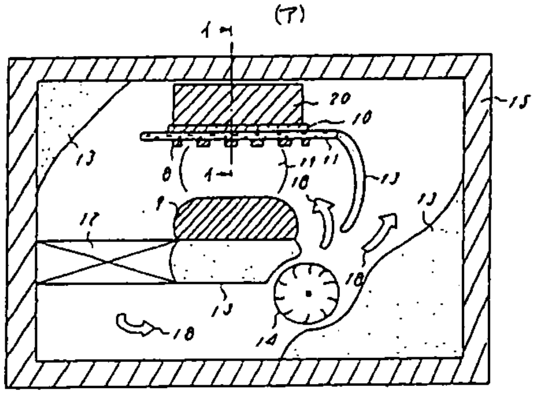
図において、(8)は第2の主電極、(9)は第1の主電極、(10)は補助電極、(11)は誘電体、(18)はレーザガス流を示す矢印、(19)は開孔部、(20)は放熱フィンである。

なお、各図中、同一符号は同一または相当部分を示すものとする。

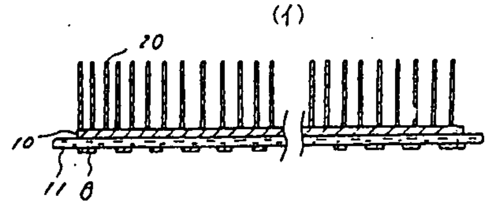
代理人　大岩増雄

第1図

(ア)

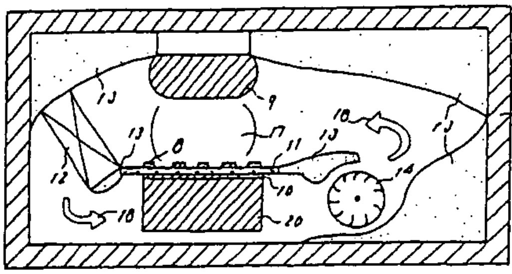


(イ)

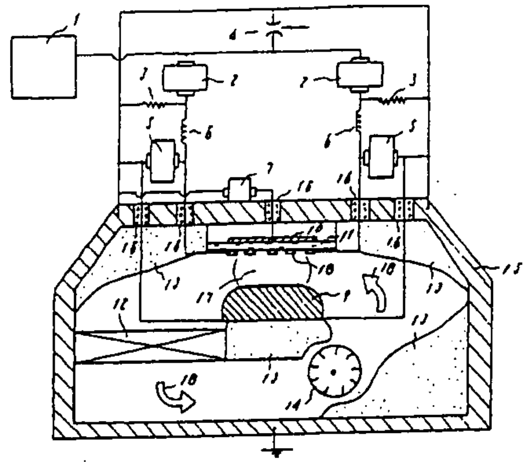


8: 第2の主電極
9: 第1の主電極
10: 補助電極
11: 誘電体
18: レーザガス流
20: 放熱フィン

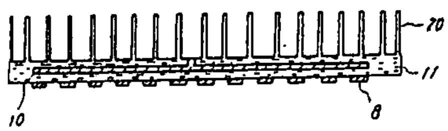
第2図



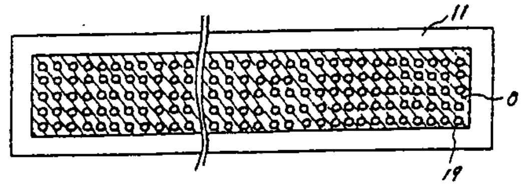
第4図



第3図



第5図



第1頁の続き
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手続補正書(自発)

昭和60年3月6日

特許庁長官殿

1．事件の表示　　特願昭59−239268号

2．発明の名称

放電励起型短パルスレーザ装置

3．補正をする者

事件との関係　特許出願人
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5．補正の対象

(1) 明細書の発明の詳細な説明の欄

(2) 図面

6．補正の内容

(1) 明細書第8頁第16行に「補助放電の開始電圧は主放電の開始電圧より低い」とあるのを「補助放電の放電開始電圧は主放電の放電開始電圧より低い」と訂正する。

(2) 同第4頁第7行〜第8行に「スイッチ(1)」とあるのを「スイッチ(4)」と訂正する。

(3) 同第5頁第18行〜第19行に「タッセルト数」とあるのを「ヌッセルト数」と訂正する。

(4) 図面の第4図を別紙のとおり訂正する。

7．添付書類の目録

図面(第4図)　1通

以上

方式審査

第4図